

Irrelevant features at fixation modulate saccadic latency and direction in visual search

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Do irrelevant visual features at fixation influence saccadic latency and direction? In a novel search paradigm, we found that when the feature of an irrelevant item at fixation matched the feature defining the target, oculomotor disengagement was delayed, and when it matched a salient distractor more eye movements were directed to that distractor. Latency effects were short-lived; direction effects persisted for up to 200 ms. We replicated latency results and demonstrated facilitated eye movements to the target when the fixated item matched the target colour. Irrelevant features of fixated items influence saccadic latency and direction and may be important considerations in predicting search behaviour.

Keywords: Attention capture; Contingent capture; Attentional disengagement; Saccadic latency; Eye movements.

Visually distinct or unique items such as colour, luminance, and motion singletons capture attention even when these properties do not predict the presence or location of a search target (e.g., Christ & Abrams, 2006; Franconeri & Simons, 2003; Jonides & Yantis, 1988; Theeuwes, 1994). Irrelevant objects that are visually similar to search targets also capture attention even when they occur at a time and/or location the target can not, an effect called contingent capture (Folk, Leber, & Egeth, 2002; Folk, Remington, & Johnston, 1992). Both capture effects are typically studied in search paradigms in which the attention-capturing item is in the periphery and therefore forces a shift of spatial attention (see Rauschenberger, 2003, for review). Little research has examined the effect of irrelevant features at

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fixation on the subsequent deployment of attention (but see Ghorashi, Zuvic, Visser, & Di Lollo, 2003; Folk, Leber, & Egeth, 2008). This is an important oversight because both the *pull* of attention to a location and the *hold* of attention at a location are determinants of visual processing.

Recently, Brockmole and Boot (2009) examined whether colour singletons, known to draw overt spatial attention to peripheral locations (Irwin, Colcombe, Kramer, & Hahn, 2000), also hold attention when presented at fixation. Participants viewed displays with homogeneously coloured task-relevant items in the periphery. An irrelevant item was presented at fixation. When this fixated item was a colour singleton, participants were slower to initiate an eye movement to peripheral items (i.e., saccade latencies were longer), but only when the singleton occurred unexpectedly. Although necessary, a violation of expectation was not sufficient to delay shifts of attention; surprising nonsingleton items did not hold attention. Findings suggested important contributions of both bottom-up and top-down factors.

Here we considered the degree to which irrelevant objects at fixation influence oculomotor/attentional disengagement when their properties are related to an observer's goal (i.e., contingent capture). Participants searched for a colour that designated the target, and a task-irrelevant item at fixation matched or mismatched the target colour. Based on the contingent capture literature, items that match an observer's attention set may be difficult to disengage from, and if so, prolonged saccade latencies should be observed when the central item matches the target colour. Furthermore, we examined whether irrelevant features at fixation influence saccadic direction. Specifically, we examined whether goal-consistent features of irrelevant objects at fixation might facilitate eye movements towards the target and whether goal-inconsistent features might drive eye movements towards similar coloured distractors.

EXPERIMENT 1

Methods

Forty Florida State University undergraduates engaged in a search task while their eye movements were recorded with an EyeLink 1000 (SR Research, Inc). Nineteen participants searched for red targets and twenty-one searched for green targets.

Observers were seated 73 cm from a 21-inch CRT display. Initially seven grey circles (1.4° radii) were presented (Figure 1). One circle was in the centre of the screen and the six remaining circles were located 7.8° into the periphery. A black fixation cross ($0.8^\circ \times 0.8^\circ$) was present within the central

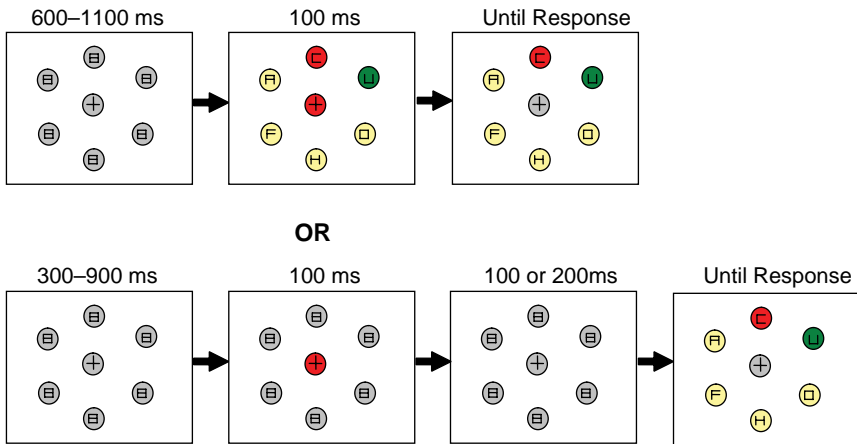


Figure 1. Example of the displays view by participants in Experiment 1 (not drawn to scale). To view this figure in colour, please see the online issue of the Journal.

circle and each outer circle contained a black figure-of-eight premask ($0.4^\circ \times 0.4^\circ$). We refer to this as the *premask display*. After a random delay of between 300 and 1100 ms, the centre circle became red, green, or blue for 100 ms, returning to grey thereafter. On one-third of trials, simultaneous with the colour alteration to the centre circle, the peripheral circles permanently changed colour (one to red, one to green, four to yellow) and premasks became letters (A, F, H, O, U, and C/backwards C). We refer to this as the *search display*. On remaining trials, the interstimulus interval (ISI) was varied such that the peripheral circles changed colour and letters were revealed 100 or 200 ms after the centre circle changed back to grey.

Participants were instructed to shift gaze to their designated target (red or green) as quickly as possible and to indicate whether it contained a C or backwards C with a button press. Participants were told that the centre circle was irrelevant and would never contain the target letter. Error messages were presented if participants moved their eyes before the presentation of the search display or identified the target incorrectly. Target identity was determined randomly each trial. Target/distractor locations were counter-balanced, as was the colour of the centre item. Participants completed 276 trials, equally divided between red, green, and blue centre trials and each ISI (0, 100, and 200 ms). Of primary interest were the saccade latency and direction of the first saccade that initiated search. An eye movement was classified as a saccade if its distance exceeded 0.2° and its acceleration reached 9500 deg/s^2 or its velocity reached 30 deg/s .

Results

Trial exclusion. The first 20 trials were considered practice and were not analysed. Trials were aborted if participants moved their eyes or blinked before the search display appeared (18% of trials, $SD = 10\%$). To ensure that only search-related eye movements were analysed, remaining trials were excluded from analysis if (a) participants made a manual response before an eye movement ($< 1\%$ of trials), (b) the amplitude of the initial eye movement did not exceed half the distance to a search item (5% of trials, $SD = 4\%$), or (c) saccadic latency was less than 90 ms (3% of trials, $SD = 3\%$). Trims resulted in 20% of all trials being discarded ($SD = 13\%$). This trim did not differentially discard trials from experimental conditions.

Saccadic reaction time. Saccadic reaction time (SRT) and accuracy are reported in Table 1. SRT was defined as the time between the presentation of the search display and the initiation of the first eye movement away from the centre circle. Only accurate saccades (to the target) were considered. SRTs were entered into an ANOVA with target colour (red or green) as a between-participant factor and ISI (0 ms, 100 ms, 200 ms) and centre colour (red, green, blue) as within-participant factors. This revealed an interaction between ISI, centre colour, and target colour, $F(4, 152) = 11.426, p < .001$. It was apparent that the pattern of SRTs was different in the 0 ms ISI condition compared to the two nonzero ISI conditions. To explore this interaction, the 0 ms ISI and the two nonzero ISIs were analysed separately.

0 ms ISI. SRTs for the 0 ms ISI condition were entered into an ANOVA with target colour (red or green) and centre colour (red, green, blue) as factors. This revealed an interaction between target and centre colour, $F(2, 76) = 14.54, p < .001$. Paired samples t -tests compared SRTs when the centre colour matched versus mismatched the target colour for each group. For participants searching for red targets, SRTs were longer when the centre was red compared to green (17 ms difference, $SD = 15$ ms), $t(18) = 4.74, p < .001$, or blue (16 ms difference, $SD = 20$ ms), $t(13) = 3.61, p < .01$. For participants searching for green targets, SRTs were longer when the centre was green compared to red (30 ms difference, $SD = 36$ ms), $t(20) = 3.69, p < .01$, or blue (15 ms difference, $SD = 33$ ms), $t(12) = 2.08, p = .05$.

100 and 200 ms ISIs. SRTs for the 100 and 200 ms ISI conditions were entered into an ANOVA with target colour (red or green), centre colour (red, green, or blue) and ISI (100 or 200 ms) as factors. This revealed a main effect of target colour, $F(1, 38) = 6.26, p < .05$, no effect of centre colour, $F(2, 76) = 0.39, p = .68$, and no effect of ISI, $F(1, 38) = 0.16, p = .69$. No interactions approached significance except for a Centre colour \times Target

TABLE 1

Mean saccadic reaction time and proportion of eye movements to the target as a function of target colour, centre colour, and ISI for each experiment (standard error of the mean within paraphrases)

<i>Target colour</i>	<i>ISI 0 centre colour</i>			<i>ISI 100 centre colour</i>			<i>ISI 200 centre colour</i>		
	<i>R</i>	<i>G</i>	<i>B</i>	<i>R</i>	<i>G</i>	<i>B</i>	<i>R</i>	<i>G</i>	<i>B</i>
	<i>Latency (ms)</i>								
Experiment 1									
Red	244 (7)	228 (7)	228 (8)	192 (4)	197 (5)	197 (5)	192 (4)	196 (5)	194 (5)
Green	250 (10)	279 (11)	265 (13)	214 (8)	211 (6)	214 (7)	218 (8)	212 (8)	216 (8)
Experiment 2									
Red	302 (12)	286 (15)	277 (12)	—	—	—	—	—	—
Green	259 (14)	283 (21)	262 (17)	—	—	—	—	—	—
	<i>EM to target (proportion of trials)</i>								
Experiment 1									
Red	.99 (.01)	.97 (.01)	1.00 (.00)	.96 (.01)	.96 (.01)	.97 (.01)	.98 (.01)	.96 (.01)	.97 (.01)
Green	.94 (.01)	.94 (.02)	.94 (.02)	.88 (.03)	.87 (.03)	.90 (.02)	.84 (.03)	.90 (.02)	.90 (.02)
Experiment 2									
Red	.97 (.01)	.92 (.02)	.94 (.02)	—	—	—	—	—	—
Green	.88 (.04)	.93 (.03)	.88 (.03)	—	—	—	—	—	—

colour interaction, $F(2, 76) = 2.81, p = .07$. Although not reaching statistical significance, this trend was in the opposite direction compared to the 0 ms ISI condition, suggesting instead a small facilitation effect when the centre colour was the same as the target colour.

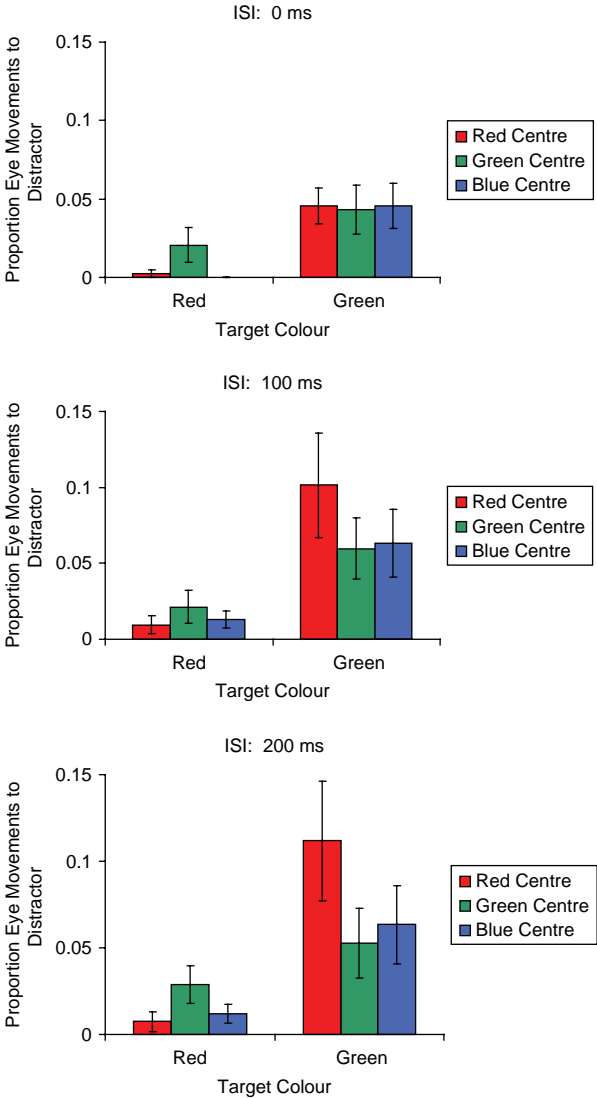


Figure 2. Proportion of eye movements to the nontarget (distractor) singleton as a function of target colour, centre colour, and ISI. To view this figure in colour, please see the online issue of the Journal.

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Eye movements to distractor. The proportions of eye movements to the salient distractor are depicted in Figure 2. A saccade was considered to be towards an item if it fell within a 60 degree wedge centred on the item. Although the effect was small, there was a consistent pattern of participants making more eye movements to the distractor when the centre item matched its colour. The same ANOVA conducted on SRTs was conducted on the proportion of eye movements to the distractor. Critically, centre colour and target colour interacted, $F(2, 76) = 9.34, p < .001$; all other interactions, $p > .14$. To examine this effect further, each group was analysed in separate ANOVAs. Participants searching for red in the presence of a green distractor were more likely to look at the distractor when the centre was green compared to red (average diff = 0.02, $SD = 0.02$), $F(1, 18) = 9.68, p < .01$, or blue (average diff = 0.02, $SD = 0.02$), $F(1, 18) = 7.20, p < .05$. Participants searching for green in the presence of a red distractor were more likely to look at the distractor when the centre was red compared to green (average diff = 0.03, $SD = 0.06$), $F(1, 20) = 7.27, p < .05$, or blue (average diff = 0.03, $SD = 0.04$), $F(1, 18) = 13.17, p < .01$.

Eye movements to target. An ANOVA performed on the proportion of eye movements that went to the target, with centre colour (red, green, blue), ISI (0, 100, or 200 ms), and target colour (red or green) as factors. This analysis did not reveal the anticipated Centre colour \times Target colour interaction, $F(2, 76) = 2.76, p = .07$, nor a significant interaction between ISI, centre colour, and target colour, $F(4, 152) = 2.16, p = .08$. Instead, these marginal trends are consistent with participants directing their eyes less frequently to the target when the centre item matched the distractor colour.

Discussion

As predicted by contingent capture effects involving the attraction of attention, the disengagement of attention was delayed when the (irrelevant) fixated item matched the target colour. These delays only occurred within a brief temporal window (< 100 ms), which contrasts with contingent capture where robust effects have been observed at ISIs up to 200 ms. Moreover, when the centre item matched the distractor's colour, participants made more eye movements to the distractor. However, when the centre item matched the target, eye movements to the target were not facilitated (possibly because of a ceiling effect which we address in Experiment 2). Results demonstrate that irrelevant objects at fixation influence both saccade latency and direction. An additional experiment examined potential target facilitation effects.

EXPERIMENT 2

It is possible eye movements were not facilitated (in terms of accuracy) towards the target in Experiment 1 because the search target was too easy to find. We increased search difficulty by making displays more heterogeneous. Search displays contained the target colour and five unique colours instead of one salient distractor. Following from the observations in Experiment 1, only the 0 ms ISI was included.

Methods

Fourteen undergraduates searched for red targets and thirteen searched for green targets. Premask displays were identical to Experiment 1. After a random delay between 500 and 1750 ms, the search display was presented. Simultaneously, all circles changed colour and premasks became letters. Peripheral circles each became a different colour (aquamarine, brown, orange, purple, tan, and, depending on condition, red or green). The centre circle was red, green, or blue, resulting in conditions in which the centre item matched the target, or in which the centre item did not match any other item. Unlike Experiment 1, the centre circle did not revert to grey. All other aspects of the task were identical to Experiment 1. Participants completed 216 trials equally divided between red, green, and blue centre trials.

Results

Trial exclusion. The first 20 trials were considered practice. Trials were aborted if participants moved their eyes or blinked before the search display appeared (16% of trials, $SD = 13\%$). Remaining trials were excluded if: (a) Participants made a manual response before an eye movement (1% of trials, $SD = 1.6\%$), (b) saccade amplitude did not exceed half the distance to a search item (7% of trials, $SD = 9\%$), and (c) saccadic latency was less than 90 ms (< 1% of trials). Trims resulted in 23% of all trials being discarded ($SD = 16\%$).

Saccadic reaction time. SRTs (Table 1) were entered into an ANOVA with target colour (red or green) and centre colour (red, green, blue) as factors. This revealed an interaction between target colour and centre colour, $F(2, 50) = 14.89, p < .001$. For participants searching for red, SRTs were longer when the centre was red compared to green (difference = 16 ms, $SD = 19$ ms), $t(13) = 3.15, p < .01$, or blue (difference = 25 ms, $SD = 17$ ms), $t(13) = 5.51, p < .001$. For participants searching for green, SRTs were longer when the centre was green compared to red (difference = 24 ms, $SD = 27$ ms), $t(12) = 3.17, p < .01$, or blue (difference = 21 ms, $SD = 24$ ms), $t(12) = 3.15, p < .01$.

Eye movements to target. The proportion of eye movements to the target were entered into an identical ANOVA (Table 1). This revealed an interaction between target colour and centre colour, $F(2, 50) = 7.79, p < .01$. For participants searching for red, accuracy was significantly higher when the centre was red compared to green (difference = 0.04, $SD = 0.04$), $t(13) = 3.83, p < .05$, and there was a trend in the same direction when the centre was blue (difference = 0.03, $SD = 0.06$), $t(13) = 1.94, p = .08$. For participants searching for green, accuracy tended to be higher when the centre was green compared to red (difference = 0.05, $SD = 0.09$), $t(12) = 1.93, p = .08$, and was significantly higher compared to when the centre was blue (difference = 0.05, $SD = 0.05$), $t(12) = 3.48, p < .01$.

Discussion

Replicating Experiment 1, latencies were prolonged when the centre item matched participants' attention set. Furthermore, participants were more accurate at saccading to the target when the fixated item matched the target colour, providing additional evidence of the impact of irrelevant features at fixation on latency and direction.

GENERAL DISCUSSION

Two experiments demonstrated that completely irrelevant items at fixation modulate oculomotor disengagement and saccade direction depending on their visual properties. Delayed disengagement was observed when the fixated item matched the target's colour even though it was known to be irrelevant. Eye movements were also more likely to move to items matching the features at fixation, whether that be the target or a distractor.

Potential mechanisms for these effects are worth further examination. A mechanism akin to contingent capture, making it more difficult to disengage attention from objects matching an observer's attention set, is one explanation. However, the time course of the SRT effect was inconsistent with contingent capture (robust effects are often observed at 200 ms). Whether a single mechanism underlies the prolonged latencies observed here and traditional contingent capture effects is uncertain. An alternative explanation may be the refocusing of covert attention. This account holds that before the presentation of search items, attention is in a diffuse state in order to detect the peripheral target. Target-consistent information at fovea may refocus covert attention at fixation, delaying oculomotor disengagement.¹ Regardless, the present work strongly suggests that goal-oriented attention sets are applied to

¹ We thank Andrew Leber for suggesting this possibility.

gaze decisions even for objects known to be task irrelevant. Although task-relevance may play an important role in effects observed here, bottom-up mechanisms may also contribute. The presence of target-defining features at fixation may reduce the salience of the peripheral target, making it more difficult to saccade to. Perceptual grouping by colour may also play a role, suggested by the fact that disengagement was only delayed when centre and peripheral items were presented simultaneously.

Saccade direction effects may be similar to priming effects in the visual search literature. A target is often found more quickly when attention was directed to targets of the same colour on previous trials (Maljkovic & Nakayama, 1994). Eye movements may have been primed in a similar manner. In this case, attention was directed to the target-defining feature on some trials because it was within the focus of attention (at fixation). Some have suggested the encoding of objects into visual short-term memory may be somewhat automatic (Olson, Moore, & Drowos, 2008), raising the possibility that memory representations of the centre item induced automatic shifts of attention to similar items (Soto, Hodsoll, Rotshtein, & Humphreys, 2008). Finally, most search models postulate a target template involved in attentional guidance and target recognition. This template may have been primed by (or been interfered with) feature information presented at fixation. Most intriguing are dissociable effects on latency and direction: All ISI conditions modulated saccade direction, but only the 0 ms condition modulated latency. Results suggest multiple mechanisms may be influenced by irrelevant visual features at fixation.

Regardless of mechanism, these results have important implications for models of search. Many models posit feature-based guidance to potential target objects (e.g., Wolfe, 1994). Our results suggest an automatic bias to fixate items similar to items already fixated. Previously fixated items are likely to be similar to the target, which would result in a bias to saccade to other target-like items. Results also suggest there may be a cost to overcome in terms of search speed. How the visual system might utilize this bias and overcome saccadic reaction time costs is a promising and fruitful topic of future research.

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